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Culture of Entomophagous Insects[1]

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"When we consider what immense services hymenopteron insects render to agriculture, it is surprising that those states that have spent already such large sums of money to fight noxious insects and that have lost still more through their depredation have never tried to raise ichneumon flies by the million and let them loose wherever there are any insect pests to destroy." Felix Gillet., Hort. Comm., El Dorado, California, 1882.

Incomplete natural control of pests that possess potentially effective natural enemies usually results from such enemies not being present in an active condition and in sufficient numbers to effect control at a time when the pest is susceptible to attack. Such enemies may be useful, however, if they can be cultured in large numbers and if the natural lack of synchronization between the two populations can be counteracted artificially by properly timed periodic liberations.

The liberation of an entomophagous insect population is usually designed either (1) to establish a new species having a controlling effect on the host or (2) to add to an established population in the hope that it will increase and achieve control more rapidly than the initial colony or (3) to produce immediate control by liberating numbers sufficient to check the increase of the host or actually reduce its density (Flanders 1930b) immediately, i.e., without further multiplication of the natural enemy. The last named procedure may be called the inundation or saturation method.

Success of the inundation method, with its system of periodic liberation is largely dependent on economy of production and liberation. Effective inunda-

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tive liberations of parasites can be made economically only when the host density is low and are usually successful only when the number of individuals released within the area which they can cover exceeds the number of host individuals therein. The possibility of substituting, for the periodic applications of insecticides, entomophagous insects periodically released in inundative numbers, has been greatly enhanced by recent developments in the technique of culturing them. The purpose of this paper is to discuss the various types of culture methods and to describe the materials and procedures involved.

Culture Methods Based on the Source and Kind of Host Material

Field-Collected Host Material.—In the biological control of some insect pests it is most economical to mass-culture their natural enemies on field-collected host material. This is particularly true in the introduction of foreign entomophagous species, since the host usually is abundant in the area to be colonized.

Field collection of the eggs of the gypsy moth, *Porthetria dispar* (L.), is practical and economical since the eggs are deposited in large masses, mainly on the trunks of trees, and persist from midsummer to the following spring (Crossman 1925).

The habit of the range caterpillar, *Hemileuca oliviae* Ckll., of depositing its eggs in masses of several hundred in the form of cylinders around grass and weed stems also permits economical field collection (Frankenfeld and Barnes 1933).

The European earwig, *Forficula auricularia* L., after attaining its third instar is readily collected in large numbers by means of artificial hiding places (Getzendaner 1936).

Aphids such as the poplar gall aphid, *Pemphigus populi-transversus* Riley, can often be collected in quantities. Such material may be used in the mass culture of aphidophagous coccinellids, since it can be stored for months at freezing temperatures and high humidities (Haug 1936).

The largest rearing program undertaken with field-collected material has been with the spruce sawfly parasite, *Microplectron fuscipennis* (Zett.), in Canada (Wilkes 1947). Cocoons of the sawfly *Gilpinia hercyniae* Htg., containing the larval and prepupal stages are collected from the forest floor and carefully cleaned and graded. Each cocoon is exposed to parasitization by one mated parasite female in a glass vial. All the progeny of this female may develop in a single cocoon. Using the vial method, with an inoculation ratio of one female parasite to one selected cocoon, twenty workers can handle a production of 2 million parasites per week at a total cost of $100 per million. During the ten-year period 1935 to 1945, over 889 million parasites were released over the spruce-sawfly infested area. Labor costs can be greatly reduced by mass parasitization; however, an inoculation ratio of 5,000 Microplectrons to 3,000 sawfly cocoons has been used successfully by Frank E. Miller (1940).

Laboratory-Reared Natural Host Material.—In the utilization of an established or indigenous entomophagous species, an inexpensive method of mass-culturing the host insect is essential, since an extraordinary large number of the natural enemy is needed.

The first biological control project based on the mass culture of the host insect was developed in 1916, when the California State Department of Agriculture undertook the propagation of mealybugs (*Pseudococcus* spp.), on bleached potato sprouts, for use in the mass culture of the coccinellid *Cryptolaemus montrouzieri* Muls. (Smith and Armitage 1931). In southern California the mass culture of *Cryptolaemus* has been continuous for about thirty years. In 1946 the combined production of seven *Cryptolaemus* insectaries was 40 million (Woglum 1947).

The mass culture of the chalcidid *Leptomastix dactylopii* How. on the mealybug *Pseudococcus citri* (Risso) has been in progress at the Associates Insectary at Santa Paula since 1935. This parasite is released on citrus trees with incipient infestations of *P. citri*. The annual output at present exceeds 10 million parasites.

In an attempt to control the tick *Dermacenter andersoni* Stiles in Montana, ticks were reared on rabbits. While on the rabbits, the ticks were exposed to parasitization by *Hunterellus hookeri* How. for 4 to 5 hours. Parasites liberated in 1928 numbered approximately 381,000 (Morton 1929).

The mass culture of the black scale, *Saissetia oleae* (Bern.), on green potato sprouts and on oleander, for use in the mass culture of the chalcidid *Metaphycus helvolus* (Comp.), has been in progress at the insectary of the Fillmore Citrus Protective District since 1937. The annual output at present is more than a million parasites.

The polyembryonic chalcidid *Copidosoma koehleri* Blanch., which was introduced into the United States from Chile in 1945 by the Commonwealth Bureau of Biological Control, was for a few months reared on the potato tuber moth at Riverside, California, at the rate of 10,000 per pound of egg-sized potatoes. Hundreds of thousands were released from a motor vehicle moving rapidly through host-inhabited areas.

Laboratory-Reared Factitious Host Material.—The natural host is not always amenable to propagation in quantities under laboratory conditions, so that the culture of its natural enemies may depend upon the use of a factitious host, that is, one that it does not attack under natural conditions.

In 1924 the egg parasite *Trichogramma* was reared experimentally on such factitious hosts as *Cimex lectularius* L. and *Ephestia kuehniella* Zell. (Hase 1925). The Angoumois grain moth, *Sitotroga cerealella* Oliv., was the first factitious host utilized in mass cultures, however. *Sitotroga* was used in 1926 as a host of *Trichogramma*, which was propagated by the Saticoy Walnut Growers Association of Ventura County, California, for release against the codling moth on walnuts (Flanders 1929, 1930a). This method was further developed by the United States Department of Agriculture so that it is now possible to produce a million *Trichogramma* a day, at a cost of $6.50 per million (Spencer, Brown, & Phillips 1935).

The potato tuber moth, *Gnorimoschema operculella* Zell., has been propagated in large numbers by the University of California for use in the mass culture of the oriental fruit moth parasite *Macrocentrus ancylivorus* Roh. (Flanders 1943c). During the 1947 season, more than 28 million *Macrocentrus* were produced, a production greatly in excess of that possible with its natural host, *Ancylis comptana fragariae* W. & R. The potato tuber moth also serves as a laboratory host for the corn-borer parasite *Cremastus flavoorbitalis* (Cam.). The potato tuber moth egg yields larger *Trichogramma* than does the egg of *Sitotroga* (Flanders 1945c).

According to Simmonds (1944), there are two types of factitious hosts: type 1, which stimulates the deposition of eggs by parasite or predator, and type 2, which does not do so but which is suitable for the normal development of the parasite or predator. The Mediterranean flour moth, *Ephestia kuehniella*, has been successfully used as a type-1 host for three species of *Chelonus* and several species of *Microbracon* (Bradley 1941). *Ephestia kuehniella* is also a type-2 host suitable for the mass culture of the codling moth parasites *Cryptus sexannulatus* Grav., *Ephialtes caudatus* Ratz., and *Aenoplex carpocapsae* Cush. The utilization of a type-2 host necessitates the use of either a natural host as a "trap" host or a

simulated natural oviposition site in order to obtain the eggs of the entomophagous insect for transfer to the factitious host. The transfer of parasite eggs from "trap hosts" was used in the mass culture of the corn-borer parasite *Exeristes roborator* Fab. (Baker & Jones 1934).

Culture Requirements

Limiting Factors.—The mass culture of any insect is contingent upon its amenability or preadaptation to artificial conditions, and upon the availability of its food. The first step in ascertaining the limitations of a project is a biological study of the species concerned, a study to determine the habitudinal characteristics that preadapt them to an artificial environment. Some species (*Perisierola emigrata* Roh., for example) are amenable to individual culturing but not to culturing *en masse*.

The facility with which preadapted entomophagous species are cultured is determined in part by the accessibility and mobility of the host stages attacked. The external parasites of relatively large hosts kill or paralyze them before oviposition.

Univoltine parasites of single-brooded hosts, or of hosts that undergo diapause, are difficult to mass-culture economically because of the low rate of turnover and the amount of space and time involved in production. A high rate of turnover is essential to insure freedom from pest organisms and to attain maximum production of host and parasite. This may be accomplished by utilizing host populations in each of which the individuals are equal in development (Finney, Flanders, Smith 1947; Flanders 1947).

In enclosed spaces the oviposition efficiency of the parasite may be reduced because of (1) the diffusion of host odor and consequent obliteration of odor gradient; (2) the absorption of host odor by other objects (Flanders 1944c) and (3) with super-abundance of parasites mutual interference with the processes of host-feeding and egg-deposition.

In general, the problems involved in the mass culture of a preadapted entomophagous insect include (1) obtaining a host-supporting medium that is abundant and cheap, (2) finding a readily reared host, (3) providing conditions which will yield the maximum number of entomophagous females per unit of time,[3] and (4) synchronizing production with the requirements for field liberation.

Host-Supporting Media.—The ideal host-supporting medium is one that is (1) nutritionally complete, (2) always available for use at low cost, (3) readily handled, and (4) slow to deteriorate.

Host-supporting media that have been found useful for the culture of certain insects and mites are listed below:

Dry plant tissues (grains, seeds, fruits) for stored-products insects, and corn meal for *Pyroderces rileyi* Walsm.
Sugar beet roots for soft scales
Sago palm for long-tailed mealybug and black scale
Oleander and potato sprouts (green) for black scale
Squash, yucca, citron melon, and potato tubers for diaspine scales
Citron melon for soft brown scale and long-tailed mealybug (Flanders 1944a)
Potato tubers for cutworms and tuber moth
Potato sprouts (bleached) for mealybugs

The dry seeds of certain plants are well suited to host propagation. This type of medium supports a relatively large number of insect species. The size and

[3]The housing and handling of cultures is determined by the scope of operation and the facilities available. Use of structurul materials such as redwood and cedar which emanate terpenoid vapors should be avoided.

moisture content of the seeds may affect their usefulness, however. In the propagation of *Sitotroga cerealella* Oliv., the total production per unit weight of grain is reached much more rapidly with wheat than with corn, apparently because of the internecine action of the larvae. Since a kernel of grain, irrespective of its size, is usually inhabited by only one *Sitotroga* larva at a time, the smaller the kernel the more rapidly it is utilized and consumed. The advantages derived from a rapid turnover of material more than offset the additional labor involved (Flanders 1934).

The sugar beet holds promise as a suitable medium for leaf-feeding insects and mites. The oleander has been used for a number of years by the Fillmore Citrus Protective District as a medium for propagating the black scale. The citron melon has been used for the propagation of the soft brown scale, *Coccus hesperidum* L. (The handling of the melon is facilitated if it is tightly banded with 1-inch mesh chicken fencing.)

The potato holds the lead as a medium for propagating insects to serve as laboratory hosts. Varietal differences in the potato affect its usefulness. Bliss Triumph produces the best sprouts for culturing mealybugs and black scale, White Rose is most suitable for culturing red scale, and Idaho Russet for tuber moth.

The potato was first used in Russia when Pospielov (1913) used sliced potatoes in the propagation of the cutworm, *Euxoa* sp., in order to obtain eggs for the culture of *Trichogramma* for use against the apple codling moth. In 1916 Smith (Branigan 1916) developed a method for propagating various species of mealybugs (*Pseudococcus* spp.) on potato sprouts lacking chlorophyl (grown in the dark), and for propagating the black scale, *Saissetia oleae*, on potato sprouts possessing chlorophyl (grown in the light). Mealybugs infesting potato sprouts have been used for the mass culture of *Cryptolaemus montrouzieri*, *Leptomastix dactylopii*, *Coccophagus gurneyi* Compere, *Tetracnemus pretiosus* Timb., and many other natural enemies. Black scale on potato sprouts has been used for the mass culture of *Metaphycus helvolus*, *M. stanleyi* Compere, *Coccophagus heteropneusticus* Compere, and others (Flanders 1942). Aphis on potato sprouts have been used at intervals in the Riverside insectary of the University of California Division of Biological Control for the propagation of *Lysiphlebus*.

In 1943 the potato tuber moth, *Gnorimoschema operculella*, which is a pest in insectaries propagating mealybugs, was found to be a suitable host for the mass culture of *Macrocentrus ancylivorus*. The egg-sized potato tuber became the base food in the culture of *Macrocentrus*, more than 200,000 pounds being used for this purpose in 1947 in insectaries in eastern and western United States.

In the fall of 1946 the smooth-skinned potato tuber came into use as a host-supporting medium for diaspine scale insects such as *Hemiberlesia lataniae* Sign. and the red scale, *Aonidiella aurantii* Mask. (Flanders 1947). The potato tuber proved to be more suitable for the mass propagation of red scale than plants previously used, such as date palm seedlings, iris plants, sago palm, and the fruits of Citrus, Citrullus, and Cucurbita.

The potato is an excellent example of a host-supporting medium for the following reasons:

(1) It eliminates the necessity for providing facilities for host-plant propagation, since an adequate supply of the tuber can be purchased cheaply in the open market throughout most of the year.

(2) It can be held in cold storage for a year or more if necessary.

(3) It can be housed so that it provides a large scale-supporting area per unit of space.

(4) Without loss of viability, it can support, for five months, a scale infestation covering its entire surface. Since the mature red scale produces young over a period of a month or more, its efficient use requires that it inhabit a host plant which remains viable during this period at least.

(5) It is more suitable than other media for artificial infestation with scale, as well as for self-infestation, and can be infested readily without wastage. The variety of potato affects the amount of infestation and of parasitization (Flanders 1945b), a flat type of potato, such as White Rose, being especially suitable.

(6) Loss of scale due to deterioration of food plant is less with the potato than with melons or squash.

(7) Host-infested potato tubers, being readily handled in compact units, are most efficiently exposed to parasitization.

(8) It permits utilization of self-perpetuating host-parasite populations housed so that the processes of infesting, parasitizing, and collecting of parasites are automatic.

(9) It can be completely infested with scales of equal age, permitting a maximum production of natural enemies in the minimum of time and space.

(10) Potatoes being in small units facilitate the liberation of immature entomophagous insects.

Disadvantages in the use of the potato are (1) the extraordinary care that must be taken to obtain mature tubers free from disease and (2) the necessity for fumigation with methyl bromide to insure freedom from tuber moth and mealybugs when such insects are pest organisms.

A recent advance in the mass culture of entomophagous insects is the use of artificial media for the propagation of the host (Theron 1947). Artificial media for the culture of houseflies, blowflies, and *Drosophila* have been in use for years and are well standardized. A medium consisting of oatmeal porridge lightly infected with the mold *Mucor hiemalis* Wehmer has been used successfully in propagating the false codling moth, *Argyroploce leucotreta* Meyr. (Ripley, Hepburn, and Dick 1939). The onion and cabbage maggots *Hylemya antiqua* (Meig.) and *H. brassicae* Bouché have been successfully reared on an agar medium with an infusion of onion and cabbage (Eyer 1921). Theron (1947) suggests the selection of host strains adapted to artificial breeding conditions.

As pointed out by Simmonds (1944) the possibilities of propagating hosts on artificial media and parasites on unnatural hosts are of great practical importance in the breeding of parasites in biological control work. Such breeding is extremely unlikely to interfere with the establishment of an introduced species, for the parasites bred in such a way are still capable of attacking their natural hosts in the field.

Qualifications of the Laboratory Host.—The ideal laboratory insect host (1) is a general feeder, (2) has a rapid rate of increase (a short life cycle and high fecundity per female), (3) exhibits little if any internecine action, (4) is highly immune to disease, (5) produces no by-products (sticky secretions, webbing, wax) to interfere with the attack of the entomophagous species, and (6) is readily accepted by the species which is to be mass-cultured.

The coccid *Hemiberlesia lataniae* has most of the qualities of the ideal host and is a perfect laboratory host for predators of red scale. It reproduces without males, and the females are robust and highly fecund. It is, however, highly susceptible to attack by the mite *Hemisarcoptes malus* Shimer.

The newly hatched scale "crawlers" of many coccids such as *Saissetia oleae*, *Coccus hesperidum*, and *Icerya purchasi* Mask. are positively phototropic and

therefore may be readily collected in quantities by placing the parental material in a box so constructed that light enters horizontally from one direction. The crawlers then migrate toward the light. If the light enters through a V-shaped opening an inch or so above the floor of the box, the crawlers converge to a point where they are blocked by a shadow, and are forced to pile up. In the propagation of mealybugs, the young are transferred from old, infested potato sprouts to fresh potato sprouts by means of temporary hosts such as leaves of the pepper tree (*Schinus molle*) or of mustard. Leaves of this type are attractive to the mealybug when fresh, but they dry out quickly and thus become unattractive and cause the mealybugs to move on to the sprouts.

The potato tuber moth, *Gnorimoschema operculella*, is an excellent laboratory host despite the fact that it is subject to various diseases. If the material is handled properly, these diseases do little damage. The fact that this species normally constructs its cocoon in sand, a chemically inert material, facilitates the separation of the host and its parasites, since the sand does not react to the sodium hypochlorite that is used in dissolving the cocooning silk. The fact that oviposition by the female moth is stimulated by a certain type of cloth surface facilitates the collection of eggs.

The Angoumois grain moth, *Sitotroga cerealella* Oliv., also is an excellent laboratory host. The feeding and pupal stages occur within the kernels of grain, which can be handled in bulk and do not become matted with webbing and excreta, as is the case with *Ephestia* spp. The adults are negatively geotropic, negatively phototropic, and positively thigmotropic to such an extent that they are readily collected.

The internecine activity of host larvae usually is a detrimental factor. With *Sitotroga* this difficulty is obviated by the use of small grains. With *Ephestia kuehniella* and *Popillia japonica* Newm., the habit is expensive in labor and equipment.

Control of Insectary Pest Organisms.—Since the host-supporting media and the host serve as food material for various organisms other than those being purposefully reared, such organisms may become established in the culture as serious pests. It is most essential that the stock or mother population be kept free of pest organisms, that is, of organisms that interfere with or prevent the efficient production of the host organism.

Measures necessary to prevent contamination of the cultures are: (1) rapid turnover and destruction of used material, (2) the use of small breeding units to facilitate the detection of pests and their elimination, (3) destruction of possible sources of pests in neighborhood of laboratory, and (4) routine sterilization of all equipment and material.

Natural enemies of the pests may sometimes be used to control them. The predatory thrips, *Scolothrips sexmaculatus* Perg., has been used to control the red spider (Pacific mite), *Tetranychus pacificus* McG., which interferes with the culture of *Comperiella bifasciata* How. (Flanders 1943a). The chalcid *Acerophagus pallidus* Timb. has been used to control the potato mealybug, *Phenacoccus solani* Ferris, which interferes with the propagation of black scale. Since this parasite does not attack mealybugs that are underground, it is incompletely effective (Flanders 1944b). The bethylid *Cephalonomia waterstoni* Gahan completely eradicated an infestation of the beetle *Laemophloeus pusillus* Schôn., the larvae of which were exceptionally destructive to the eggs of *Sitotroga* (Schrad & Garman 1933).

Insecticides are used to prevent rather than to control pest infestations in culture operations.

In the propagation of *Sitotroga* the host-supporting medium (wheat) is dipped in hot water to kill possible pests, as well as to increase the moisture content of the grain. With some materials dry heat may be used. The eggs of *Sitotroga* are immersed momentarily in carbon disulphide to prevent infestation by mites (Spencer, Brown, & Phillips 1935). In the mass propagation of the false codling moth, the eggs, with embryo well developed, are treated with commercial Formalin to five parts of water (Ripley, Hepburn, & Dick 1939). In the mass propagation of the potato tuber moth, the eggs are immersed in hot water to prevent the development of microsporidia (Allen & Brunson 1947). Potatoes that are to be used for rearing red scale are fumigated with methyl bromide for 2 hours at 80°F. four days before using.

The organism most generally feared by insectary operators is the straw itch mite, *Pediculoides ventricosus* Newp. This mite is a temporary parasite of man, causing an irritating skin rash. It will completely destroy a culture of insects in a remarkably short time. Outbreaks of this mite are readily prevented by a rapid turnover of material, by sanitation, and by the use of flowers of sulfur.

Other organisms that have been detrimental in mass cultures of host insects are listed below:

Cultured species—Angoumois grain moth:	
Parasitic pest	*Dibrachys cavus* Wek.
Parasitic pest	*Habrocytus cerealellae* Ashm.
Competitive pest	*Sitophilus oryza* L.
Competitive pest	*Tribolium confusum* Duv.
Competitive pest	*Tyroglyphus* sp.
Cultured species—Mealybugs:	
Competitive pest	*Aphis* spp.
Parasitic pest	*Leptomastidea abnormis* Gir.
Predatory pest	*Sympherobius* spp.
Cultured species—Latania scale:	
Competitive pest	*Gnorimoschema operculella* Zell.
Competitive pest	Mealybugs
Predatory pest	*Hemisarcoptes malus*
Predatory pest	*Lindorus lophanthae* Blaisdell

Pests that develop only on certain host stages may be eliminated by isolating the host material equal in age so that the interval between suitable stages is sufficient to starve out the pest. This may require a period of several host generations. The mite *Hemisarcoptes malus* attacks latania scales after the newly hatched crawlers force their way out from beneath the scale covering. Red scale appears to be largely immune to attacks by this mite because the body of the female scale closely adheres to the scale covering. The best insurance against damage by such a pest is to have uniformly developed host infestations, so that there may be long periods in which there are no hosts suitable for the development of the pest. With latania scale, the mature infestations, when used for reproduction, should be utilized before a generation of the mite can complete its development.

Reproduction Factors

Mating.—The principal obstacle to the mass culture of many entomophagous species is mating, particularly in those species which usually mate in flight. In such cases special provisions for mating are necessary, and these provisions may vary as greatly between species as between families or even orders. The Chalcidoidea, however, usually mate readily without special provision (Flanders 1943b).

The females of the Tachinidae usually mate only once. Repeated matings

have been noted in several species. Mating may be induced in the Tachinidae (1) by shaking the container so as to cause the adults to tumble together; (2) by placing large numbers of the adults (males predominating) in large screen cages, outdoors, shaded from the sun; and (3) by transferring screen containers from shade to bright sunlight.[4]

The range of light intensity favorable to mating may be narrow. Species that are diurnal in habit usually mate most freely during morning hours, with increasing light and temperatures, whereas species that are crepuscular or nocturnal in habit mate as light and temperatures decline. Mating and attempted oviposition are not to be taken as conclusive evidence that the females are impregnated. In the Tachinidae the absence of eggs in the posterior uterus generally may be taken as evidence of lack of mating.

The females of the Tachinidae and Hymenoptera usually are sexually mature immediately after emergence, whereas the males show little tendency to mate until one or several days after emergence. The developmental period of the immature stages of the male is less than that of the females, however, by one or several days, so that the males are usually present and sexually mature when the females emerge. In the Hymenoptera newly emerged females, particularly those of gregarious species, mate most readily. Mating should occur during the preoviposition period to ensure maximum production. The female often loses the mating instinct; the male rarely if ever does so.

The majority of species mate most readily at temperatures of 65° to 75°F., which are below the optimum maximum for oviposition and development. Mating in containers may be inhibited if the air becomes so saturated with the odor of the females that it is not a distinguishing factor, there being no gradient by which the male is directed to the female. If the females refuse to mate under any circumstances, as with *Habrolepis rouxi* Compere, mating may be unnecessary for reproduction.

Flight may be a prelude to mating in certain species. The Opiinae, particularly, are difficult to mate in indoor cages. Use of large outdoor cages, if shaded, may be satisfactory.

Macrocentrus females under normal conditions mate but once. Conditions that enable females to mate several times cause them to produce more male than female progeny (Flanders 1945a).

Females that are unmated because of aging or other unfavourable conditions may be induced to mate (1) by brushing their bodies with larval skins of newly emerged females, (2) by withholding nourishment for several hours and then presenting them with food in the presence of full-fed males, (3) by exposure to air movement produced by an electric fan, (4) by a sudden increase in temperature to the optimum in the presence of bright light, (5) by subjecting them to anaesthetization or by chilling and subsequently confining them with males immediately after recovery but before regaining full activity, or (6) merely by having a certain ratio of males to females.[4]

Inbreeding.—The reproductive qualities of an entomophagous insect under mass culture are not adversely affected by continuous propagation, generation after generation, under the same conditions.

Degeneration of breeding stock has been reported from time to time, but an investigation has in each case shown it to be an effect of improper handling. A decline in proportion of females in successive generations, to the point of extinction, such as has occurred in the cultures of certain braconids and ichneumonids, is remedied by handling the material so that the female upon receiving

[4]Clausen, C. P. Unpublished notes.

the spermatophore from the male is able to adjust it and become impregnated.

Inbreeding has no effect on the fecundity of the female. In many species, under natural conditions, inbreeding is the rule, particularly in gregarious species such as those of *Melittobia* and *Telenomus*, which mate before emerging from their hosts. In fact, observations by Schmieder & Whiting (1947) indicate that with *Melittobia* inbreeding increases fecundity.

Selective breeding for fecundity under culture conditions appears to be of little if any value, since in most cases the food supply is fully utilized. Simmonds (1947) and Wilkes (1947) report that selective mating can be used to increase the proportion of females in cultures in which the sex ratios have been declining. Selective breeding in the insectary, however, may establish characteristics that would be unfavorable to survival in the field.

The efficiency of culture operations is measured by the number of entomophagous females reared per unit of space. This depends, in part, upon the sex ratio. With species of the Coccinellidae and of the Tachinidae, the sexes are represented equally in the deposited eggs. With biparental Hymenoptera, however, the sex ratio of deposited eggs is extremely variable. Under conditions of cannibalism or of superparasitism a differential mortality of the sexes may affect the sex ratio.

Regulation of the Sex Ratio.—In the culture of biparental parasitic Hymenoptera, the stage of host development and host density may determine the sex ratio, provided the parental females have been successfully mated. Females of such species as *Typhia popilliavora* Roh. and *Metaphycus helvolus* tend to deposit male-producing eggs on small hosts and female-producing eggs on large hosts. Females of *Coccophagus ochraceus* How. tend to produce more male progeny than female when host density is high. The normal sex ratio of gregarious species like *Microplectron* is more likely to be modified by the condition of the individual host than by host density.

Male Hyperparasitism.—With many hymenopterous species of the aphelinid group, the male develops only as a hyperparasite of the female. Consequently, in such species there is a tendency for female populations to alternate with male populations. Particular attention should be given to the mating of such species so that the liberations may consist of mated females.

Nutrition.—With some entomophagous species, propagation under artificial conditions requires special attention to nutrition. Oviposition by the adult green lacewing, for example, can be regulated by her supply of honeydew produced by mealybugs. After a preoviposition period of two weeks, normal oviposition can be induced only by feeding on honeydew. Thereafter, when honeydew is withheld, oviposition immediately begins to decrease to a mere trace, although the female may be feeding heavily on bee's honey (Finney 1948).

Maximum oviposition by many parasitic Hymenoptera and Diptera requires daily feeding on carbohydrates such as bee's honey. When undiluted honey is used for food, the relative humidity should range between 50 and 60 per cent. the honey should be placed in fine streaks or droplets on a non-absorbent base.

Humidity.—Humidity requirements vary with the kind of insects cultured. Latania scale requires a higher humidity for successful development than red scale. The newly hatched larvae of predators such as coccinellids and lacewings are readily desiccated at low humidities. The younger stages of Hymenoptera are usually protected, so that low humidities are generally less injurious to development with culture of Hymenoptera than in those of coccinellids. With species like *Macrocentrus*, however, oviposition does not occur at low humidities (Martin 1946a). The olfactory recognition of the host by the parasite may

depend on the amount of water vapor in the air (Flanders 1944c). High humidity favors the development of the sugar mite, which is highly destructive to the quiescent stages of coccinellids. A relative humidity of 55 to 65 per cent is usually satisfactory for the culture of entomophagous insects.

Temperature.—In order to obtain maximum production per unit of time the rearing temperatures should be such that normal development proceeds with maximum rapidity. Although developmental response to temperature may vary with different species, rearing temperatures between 80° and 85°F. are usually satisfactory. An increase in the developmental rate of the parasite by using temperatures that lower the fecundity of the species may increase production. In *Trichogramma* production, for example, the shortening of the life cycle at temperatures of about 86°F. more than offsets the higher productivity *per female* at 77°F. (Lund 1938).

Mutilation.—Parasitic Hymenoptera often use the ovipositor as an instrument for mutilating the viscera of the host. This is usually done in preparation for feeding on the contents of the host. This habit, however, may become pernicious and completely prevent reproduction when the parasites are presented with hosts before such hosts are large enough for the development of the offspring of the parasite. *Aphytis chrysomphali,* an ectoparasite of red scale under mass culture, has thus completely destroyed a host population, no reproduction of either host or parasite occurring (Glenn L. Finney. Unpublished notes). Females of *Aphytis* spp. may destroy the full fed larvae and pupae of their own species by mutilation.

Superparasitism.—In mass cultures superparasitism is rarely, if ever, detrimental, particularly if the optimum population ratio of host to parasite is maintained. With species in which superparasitism is normal it may be counterbalanced with a smaller inoculum. In general, the number of eggs normally deposited by a parasite on/in an individual host is largely independent of host density (Flanders 1942a).

With solitary species superparasitism may increase the proportion of female parasites reared from a given host population if the parasite species tends to deposit more female than male eggs per host (Martin and Finney 1946b, Jenni 1947). With gregarious species, however, superparasitism may result in a marked reduction in proportion of females (Moursi 1946).

Cannibalism.—In the culture of predators the control of cannibalism is one of the chief problems. The detrimental effect of cannibalism may be largely overcome by maintaining an excess of prey available to the larval stages (Merritt Hawkes 1920).

Culture Procedures

Segregation of Operations.—Three distinct operations are involved in mass culture of entomophagous insects, namely, (1) the preparation of the host-supporting medium, (2) the propagation of the host, and (3) the culture of the entomophagous species. Under artificial conditions, as under natural conditions, these operations may be more or less segregated: in the field or in very large cages, by time and space; in the laboratory, by insect-proof partitions. In the field, segregation is automatic and prevents both host and entomophagous species from committing race-suicide. Under insectary conditions, segregation permits mass culture at maximum densities.

Since in mass culture 100 per cent parasitization of the host rarely occurs, it may be necessary after parasitization is completed to separate the two populations if the hosts that escape parasitization are to be used for infesting fresh host-sup-

porting media, or if the entomophagous species is to be released in areas where the laboratory host is also a field pest.

In the mass culture of the oriental fruit moth parasite *Macrocentrus ancylivorus*, separate stock cultures of the laboratory host are unnecessary if it is propagated on the Russet variety of potato, since with this variety a relatively higher proportion of the host escapes parasitization by burrowing more deeply than with the White Rose.

Operational Factors.—For economy of operation, the developmental periods of host and entomophagous insects are shortened to the minimum in the following ways: (1) by holding the material constantly at the maximum temperatures and humidities for normal development—usually about 82°F., and at 55 per cent relative humidity; (2) by utilizing host individuals equal in development; and (3) by obtaining maximum use of the hosts through eliminating the need for searching by the entomophagous species.

A rapid turnover of material minimizes the amount of space and equipment needed to procure a given number of entomophagous insects; the number of individuals produced per unit of space and time is a criterion of efficiency of operation. The continuity of operations which is essential for the efficient use of labor and material necessitates, with entomophagous species such as *Macrocentrus*, the segregation of operations.

Handling of the Populations.—In the parasite or predator breeding rooms, as in the host breeding rooms, the ratio of inoculum (the initial number of individuals) to the amount of food available must be such as to obtain the maximum production in the minimum of time. This ratio varies greatly with the species concerned.

(a) Introduction of Prey Populations into a Predator Population.

With predator populations in which the individual consumes many hosts in order to complete development, efficient propagation may require the introduction of hosts into the predator populations, as in the propagation of *Chrysopa* sp., in which the eggs and larvae of the potato tuber moth are fed at intervals to the larval stages of *Chrysopa*. Likewise, in the culture of Coccinellids, the host material is introduced.

The nature of attack may make it necessary either to remove part of the predator population in order to prevent starvation, or to add predators, as in *Chrysopa* production, in sufficient numbers, to efficiently consume the host. Uniformity in production, a necessary condition for economical production, may require a high ratio of adult predator to host, in which case the period of exposure must be limited to prevent cannibalism.

(b) Introduction of a Predator Population into a Prey Population.

In the mass culture of *Cryptolaemus montrouzieri*, an inoculum of 20 adults yields progeny numbering about 2,000. The prey population must be sufficient to enable all the progeny to reach maturity.

(c) Introduction of Host Populations into a Parasite Population.

In the culture of parasites such as *Aphytis* spp., which attack a host species throughout a wide range of its developmental stages but can develop successfully only within a very limited range of such stages (Quayle 1910), the efficient use of the host (and consequently its food base) necessitates it being exposed to attack only when in the stages of the limited range. This can be done only by segregation of operations. Consequently considerable space is required for completely infesting the food base with hosts of equal age, and for storing them until they are in a stage most suitable for parasite production.

With certain parasitic species, the segregation of the parasitizing population from the emerging adult parasitic population is essential for efficient use of material. In such a case the parasite population should be replenished regularly.

Comperiella bifasciata, Chinese strain, attacks all stages of the red scale except the egg, active crawlers, and adult males. It develops most successfully, however, when it attacks the early stages of the third-instar scale. When the attack occurs in the first instar, a high proportion of both scale and parasite die without further development. When the attack occurs in the late third instar, a high population of the developing parasites may die from lack of sufficient nourishment. Consequently, the most efficient use of the scale is obtained when it is introduced into the parasite population during the early third instar. This can be done if the food base is infested uniformly with red scale of equal age.

Aphytis sp. attacks the settled red scale throughout its first and second instar and early part of the third instar, or until shortly after mating. Development under mass culture is successful only in the prepupal stage of the male scale and the early part of the third instar of the female. Attacks during the earlier stages merely result in death of the scale without production of parasites. Since the size of the host influences the size and number of parasites developing upon it, the efficient use of scale and food base by *Aphytis* may necessitate exposure of the scale to parasitism only when it is in the early third instar, provided there is little, if any, difference between the stages in susceptibility to attack.

The parasite population should be sufficient to parasitize most of the host population during a short period of exposure. The parasitized hosts are then removed and placed in closed containers for the automatic collection of the parasite adults. The habit of most parasites of concentrating in lighted areas permits efficient production in properly constructed breeding rooms. The parasite population may be drawn from areas containing parasitized hosts to areas containing unparasitized hosts by manipulation of the lighting.

(d) Introduction of Hosts Individually into a Parasite Population.

In the culture of parasites it is sometimes more efficient to introduce the host individuals into a parasite population, in which case the hosts are removed as soon as parasitized. Such a method is utilized in propagating species like the tachinids *Sturmia* sp. and *Bigonicheta setipennis*, and the bethylids *Perisierola* spp. (Allen, Holloway and Haeussler 1940; Coppel and House 1947).

(e) Introduction of a Parasite Population into a Host Population.

This method of handling is exemplified in the culture of *Macrocentrus ancylivorus* (Finney, Flanders, and Smith 1947).

If the host population under laboratory conditions is uniform in development, the period of attack by parasites may be limited and a larger inoculum made necessary. Usually it is not economical to remove the inoculum for further utilization.

The females of *Macrocentrus* are not utilized to their full capacity since they are unable to deposit their full quota of eggs before the host develops out of the stage susceptible to attack.

In cultures of *Macrocentrus* on oriental fruit moth, Van Steenburgh and Boyce (1937) increased the number of hosts parasitized, and consequently the total parasite production, by including in the inoculum an intrinsically inferior parasite, *Ascogaster carpocapsae* Vier.

(f) Contact of a Parasite Population with Host Populations Through Thin-Walled Partition.

This method is most efficient in utilizing both host and parasite populations with a minimum amount of handling. It was first used on a large scale by

Doutt & Finney (1947) in culturing *Dibrachys cavus* Walker on potato tuber moth larvae. Since this type of culture method may be applicable to many species, Doutt and Finney's description of it is quoted below:

"The stock of parasites is maintained in shallow wooden boxes fitted with tight cloth covers. . . . The adult *Dibrachys* are put into each container through the 1-inch hole in the end and additional parasites are added daily in order to maintain the population of active females. These *Dibrachys* containers serve as parasitization units.

"Mature larvae of *Gnorimoschema operculella* are used as hosts for *Dibrachys*. These larvae are collected in quantity by first permitting them to cocoon in sand on the cocooning plates placed within the electric barrier (Finney *et al.* 1947) and then freeing them from their cocoons by processing with sodium hypochlorite solution as described by Bartlett & Martin (1945) and also by Martin & Finney (1946). The larvae thus collected are immediately [coddled] immersed in a hot water bath (135°F.) for 2 minutes. This water bath also contains paraffin wax with a low melting point (43°C. to 47°C.) and a blood albumin spreader. A somewhat similar method was used by Theron (1945) to condition larvae of the codling moth for attack by ectoparasitic ichneumonids. When the larvae are removed from the water bath they are spread on wooden-framed, cloth trays about 40 by 20 inches. These trays are placed upon the cloth covers of the parasitization units and are then dampened. Upon drying, the cloth of the units and the cloth of the trays seal together. The *Dibrachys* females oviposit readily through the two layers of cloth, which deter them no more than the silken wall of any host cocoon. The host larvae, although killed by the hot water treatment and coated with paraffin wax, remain attractive to the parasites.

"The cloth trays containing the parasitized host larvae are removed from the parasitization units, daily. These are held for 14 days at a constant temperature of 82°F. At the end of 14 days the *Dibrachys* have consumed their hosts and have developed to the mature pupal stage. The *Dibrachys* pupae are separated from the remaining host material by sifting through a 16 mesh wire screen."

Entomophagous species may be handled individually, as with *Microplectron fuscipennis* or *Typhia popilliavora*, or collectively, as with *Trichogramma* or *Macrocentrus*. Individual handling increases labor costs per insect reared, although a much greater number of progeny are reared per parent. The ratio of increase, for example, is much greater in the mass culture of *Chelonus* or *Microplectron* than with *Trichogramma* or *Cryptolaemus*.

Combination of Operations, in that Host-Parasite Populations are Self-Perpetuating

With certain entomophagous species, it is feasible to combine the operations of host propagation and of culture of the entomophagous species. These operations take place within a unit which is set up more or less permanently. In such a unit infestation and parasitization are automatic (Flanders, 1948). With entomophagous insects possessing strong tropisms the use of proper equipment will make their collection automatic also.

It is possible to establish a self-perpetuating automatic-collecting population of red scale, and its endoparasite, *Aspidiotiphagus* sp. by using the potato as a food base. All the material may be housed in a cardboard box, one end consisting of a transparent, open-ended cone exposed to light, and the other end open but dark. The floor of the box should be covered with a layer of potatoes infested with parasitized scale. A layer of uninfested potatoes may then be placed upon the infested layer. Thereafter, at intervals of several months, the old potatoes

should be removed and replaced with fresh ones. The newly emerged parasites being positively phototropic move to the end of the cone and are trapped in a vial placed over the apex. The vials containing the parasites are removed daily. Enough parasites will oviposit before being trapped in the vial to maintain the culture.

The invasion of a self-perpetuating unit by a pest organism will soon destroy the culture.

Automatic collection of entomophagous insects through the utilization of their tropic responses is economical only when the population emerging per day in each culture unit is fairly uniform in numbers.

The Development of a Mass-Culture Project (*Macrocentrus ancylivorus*)

The development of the mass culture of *Macrocentrus ancylivorus* by the Division of Biological Control of the University of California during the period 1943 to 1947, inclusive, provides an interesting example of the problems involved in such a project (Finney, Flanders, and Smith 1947).

Experimental work began in March, 1943, four months after the discovery that the oriental fruit moth, *Grapholitha molesta* Busck, occurred in California. The use of the field-cage method of *Macrocentrus* production developed in the eastern United States was considered impractical from the standpoint of producing *Macrocentrus* in numbers sufficient to cover the peach-growing areas of California in the event that they should become seriously infested. Also, the strawberry leaf-roller, *Ancylis comptana fragariae* W. & R., which serves as a host of *Macrocentrus* in the east, does not occur in southern California.

The first problem was to find, if possible, an insect in which *Macrocentrus* would oviposit and develop, and which could be readily propagated in containers easily handled. Two species were available in numbers for immediate testing—the Mediterranean flour moth, *Ephestia kuehniella*, and the potato tuber moth, *Gnorimoschema operculella*. Only the tuber moth proved attractive to *Macrocentrus* and suitable for its development.

Of the parts of the potato plant habitable by the moth *Gnorimoschema operculella*, the tuber can be handled most efficiently, since it furnishes the most food in the least space. The newly hatched tuber moth larvae normally enter the potato at the "eyes," but under mass infestation the concentration of larvae at the eyes results in excessive competition, which slows up development, delays the consumption of the potato, and reduces turnover. In order to obtain maximum production in a minimum of time and space, it was necessary to add artificial "eyes"; this was done by puncturing the potatoes by rolling them between brad-studded flexible leather pads.

To facilitate the operations of infestation by the tuber moth, of exposing tuber moth to attack by *Macrocentrus*, and of collecting the cocoons of full-fed, parasitized and unparasitized hosts, the punctured potatoes were placed one layer deep on trays that were made of hardware cloth and were as large as could be handled easily.

The problem of obtaining uniform infesting material (in this case tuber moth eggs) in sufficiently large amounts was solved by the discovery that the female host preferred to oviposit on rough ventral surfaces, particularly when such surfaces consisted of a type of cloth having a fibrous nap. The ovipositing moths were placed for oviposition in a very shallow wooden box having smooth sides and floor and a removable cloth top. A method of anesthetizing the moth adults with a nonexplosive mixture of ether and carbon dioxide was developed so that the moths could be placed in the oviposition cage in measured amounts,

the dead moths removed, and the egg cloth removed and replaced without any moths escaping. The size of the egg deposition boxes was made to correspond with the potato-covered area of the hardware-cloth trays, so that the cloth bearing the moth eggs would cover the potatoes completely and permit the transfer of the newly hatched host larvae to the newly punctured potatoes.

The problem of obtaining the maximum possible parasitization of host larvae by *Macrocentrus* was solved by placing the trayed potatoes in a shallow box so constructed that the parasite inoculum would be confined to a limited space around the infested potatoes and the moisture given off by the potatoes would create the atmospheric humidity essential for oviposition by *Macrocentrus*. Prior to the introduction of the parasites into the parasitization box, the egg sheet had to be removed.

The full-fed tuber moth larvae, parasitized as well as unparasitized, have the habit of migrating to the ground and spinning their cocoons on dirt and debris. The problem of economically separating host and parasite was solved by removing the trays of infested potatoes from the parasitization boxes and stacking them over beds of plaster sand placed on waxed boards. The plates containing the cocoons, which were embedded in the sand, were removed daily so that the larvae would be equal in development, and they were held until the unparasitized larvae had pupated. Then the cocoons were immersed in a sodium hypochlorite solution to dissolve the silk and release the host pupae and the parchment cocoons of the parasite. This material was strained out, rinsed in water, and then separated by immersion in dilute alcohol, in which the host pupae settled and the parasite cocoons floated. The separation of host and parasite prior to their emergence greatly simplified handling for production, shipment, and release in the field.

The problem of confining the migrating tuber moth larvae to the cocooning beds of sand was solved by the development of the hot wire barrier.

The problem of obtaining the most favorable sex ratio was solved by the discovery that excess mating prevented the complete impregnation of the female. Excess mating was prevented by having the mating chamber unlighted and activity controlled only by temperature.

Summary

Methods for culturing entomophagous insects are of several types based on the source and kind of host material, as field-collected or laboratory-reared, natural or factitious.

Cultural requirements are discussed with respect to limiting factors, kinds of host-supporting media, qualifications of laboratory host, control of insectary pest organisms, and factors bearing on the reproduction of the entomophagous insect under artificial conditions.

Culture operations include (1) the preparation of the host-supporting medium, (2) the propagation of the host, and (3) the culture of the entomophagous species. The second and third operations may be employed either separately or in combination. When the operations are separate, the procedure is either to introduce the host as individuals or as a population into the parasite/predator populations, or to introduce the parasite into the host population, or to bring the host and parasite in contact through a thin-walled partition. When operations are combined, the processes of infestation (propagation of host) and parasitization (culture of parasite) are automatic and contained in a single operating unit.

With certain entomophagous species, collection of the reared material can also be done automatically by utilizing their tropic responses.

The development of a culture project is exemplified by a detailed account of that of *Macrocentrus ancylivorus* Roh.

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Insects Attacking *Cordia macrostachya* (Jacq.) Roem. and Schult in the West Indies

II. *Schematiza cordiae* Barb. (Coleoptera, Galerucidae)

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Introduction

This is the second of a series of papers dealing with the life-histories of a number of insects attacking the black sage, *Cordia macrostachya*, in the West Indies, where search is being made for suitable species to use in an attempt at the biological control of the weed in Mauritius (Simmonds 1949).

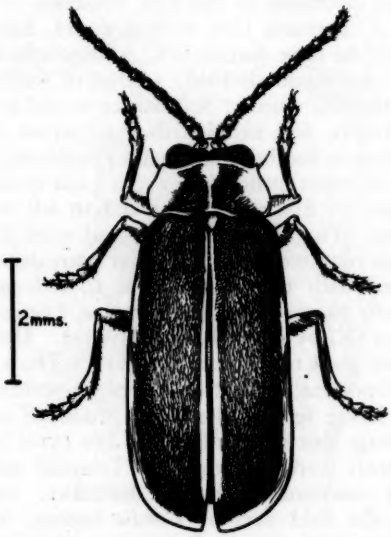

Fig. 1. Adult *Schematiza cordiae* Barb.

Schematiza, like *Physonota alutacea*, is a leaf-eating beetle, sometimes occurring in relatively large numbers on *Cordia*. It is very heavily parasitized in Trinidad, and as it appeared to be very suitable for introduction into Mauritius it was investigated in detail, both in the field and in the laboratory.

Systematic Position and Adult Characters

This species was formerly thought to be *S. lateralis* Jac. but Barber (1947) has described it as a new species, *S. cordiae* Barb., with the following description. "Opaque, fuscous, depressed, elongate oval, sides arcuate, length 6-7.5 mm., width 3-3.6 mm. Pronotum twice as wide as long, sides expanded and strongly arcuate, surface broadly impressed at lateral fourths and narrowly over occiput. Elytra smooth, evenly convex from within the prominent marginal costa to the elevated sutural costa, showing no vestige of submarginal costa characteristic of *lateralis*; sculpture and vestiture fine and dense. Antennae slightly thickened near middle, tapering apically, not flattened. Sexes extremely similar."

The systematic position and synonymy is fully dealt with by Barber (loc. cit.), and the general appearance of the adult is shown in Figure 1.

Distribution and Food Plants

Specimens of this species have previously only been identified from Trinidad and Caracas, Venezuela. During the present investigation it has been found in Tobago; it was not seen in Barbados though *Cordia* was common, and in Grenada it is represented by a very dark race or species which has, however, habits very similar if not identical to those of the Trinidadian form. In Trinidad, *Schematiza* is found all over the island wherever *Cordia* occurs and adults and larvae are commonly seen, particularly on small *Cordia* bushes and where there is a certain amount of shade.

Apart from results obtained in this investigation and the previous reports dealing with its occurrence on *Cordia* (Kirby and Adamson (1944), Donald (1945)) there are no other indications as to the food plants of *Schematiza cordiae* excepting the label on specimens in the U.S. Museum:—"on *Cordia cylindrostachya*, Caracas, D.F., Venezuela Oct. 4 1939. C. H. Ballou, No. 934." This *Cordia* is most probably the same species as *C. macrostachya* from Trinidad. As with *Physonota alutacea* (Simmonds 1949) a series of feeding tests with various plants was made to determine whether *Schematiza* would attack species of plants other than *Cordia*. Adults, first and fourth stage larvae were tested with the same 122 species of plants as had been used with *Physonota*, using the same technique, except that all the experiments were carried out in the small, cheese-cloth sided cages. Ten adults, 20 first stage larvae and 10 4th stage larvae were used with each plant species. The only plants attacked were *Cordia colococca* and *C. lockhartii*. Previous tests with *Schematiza* in petri dishes showed that some slight feeding occurred with *Cordia alliodora*, *C. colococca*, *C. dodecandea*, *C. sebestena* and *Mysotis palustris*, *Brassica oleracea*, *Phaseolus vulgaris*, *Psidium guajava*, *Lantana camara* (Kirby and Adamson (1944)). Donald (1945) obtained no feeding on any other plant but *C. macrostachya*. Trials in Mauritius showed that in petri dishes *Schematiza* larvae would feed on several plants, and that on cabbage fourth instar larvae fed, pupated, and produced adults. However, no eggs were laid on cabbage nor could the entire life cycle be completed on this plant. These experiments were duplicated in Trinidad and similar results obtained under confined conditions with high humidity. In further tests large cages were placed in the field over a) *Cordia* bushes. b) Cabbages and c) *Cordia* bushes and cabbages together. *Schematiza* larvae were placed on both *Cordia* and cabbages and the cages examined daily. In a) development proceeded normally. In b) all larvae wandered off the cabbages after making a few "nibbles" on the leaves, and subsequently died. In c) after nibbling at the cabbage a few of the larvae migrated to the *Cordia* and the rest died.

Schematiza cordiae in Trinidad thus appears to be restricted to *C. macrostachya* as its foodplant.

Biology of the Adult

Schematiza adults may be found commonly in the field in Trinidad on *Cordia* bushes during the wet season. They feed on the leaves and when disturbed may drop to the ground or fly off. In the dry season the species disappears from the bushes and it seems that, as with *Physonota*, adults become inactive at that time and rest in the debris on the ground.

When feeding adults make perforations in the leaf rather than excising pieces around the edge, any attempt made to estimate the amount of food consumed daily by the adult is rendered too inaccurate. Further, the actual damage to the leaf is probably considerably greater than the area of leaf actually removed owing to the formation of necrotic areas around the holes, and, when attack is heavy, to the killing of entire leaves that have been badly "holed".

Mating occurs readily once the cuticle of the adults has properly hardened after emergence, that is, when they are about a week old. The male, usually smaller than the female, is dorsal during mating which is of several hours duration and occurs at frequent intervals throughout life. Eggs are laid one to three days after mating and for a considerable period (4-10 weeks) after this. Unmated females often lay eggs but these are infertile.

The life of the adult may be long, and some in the laboratory have lived for six months. Under Trinidadian wet season conditions in the laboratory adults were found to live on an average:—males 103 days, females 142 days. Of 12 mated females the average total oviposition was 866, approximately 15 eggs per day during the oviposition period. The maximum number of eggs obtained from an individual female was 1571.

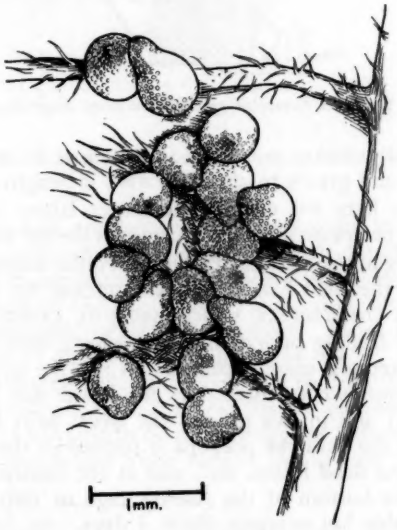

FIG. 2. *Schematiza* eggs on *Cordia* leaf.

Immature Stages

A. *The egg.*

Eggs are laid in irregular batches on either side of the leaves of *Cordia* (Figure 2). They may be laid fairly contiguously or may be scattered, and the number of eggs in a batch varies, but is on an average about 30 (66 maximum observed). As each egg is laid, a viscous fluid is poured over it so that it adheres to the leaf surface and to adjacent eggs. This fluid hardens as it dries. The individual eggs (Figure 3) are pear-shaped, .5 mm. at the broadest part, and they are attached to the leaf surface at the broader end. Eggs are fawn-yellow when laid but darken considerably as they dry after laying, and the surface has an irregularly reticulate sculpturing. If allowed to remain in a dry atmosphere the eggs are quickly killed and least mortality is seen in the laboratory when egg-masses are kept in vials or dishes with damp blotting paper. Under these conditions eggs hatch in 3-4 days.

B. *Larval stages.*

The larva hatches by cutting a circular hole in the apex of the egg and eating away part of the egg-shell. Larvae remain clustered around the egg-mass

before beginning to feed; this consists of gnawing off the outer layers of the leaf surface.

The first stage larvae are pale yellow 1.5-2.0 mm. in length. There are paired processes on each segment bearing pale hairs. The general shape of the larva is shown in Figure 4. At the posterior end there is a clasper which is used as an aid to locomotion.

The second stage is similar to the first except that it is somewhat darker and 3-4 mm. in length. The third stage is similar but has paired segmental patches

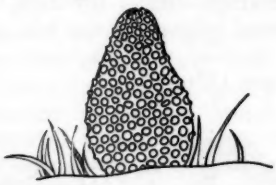

FIG. 3. Single *Schematiza* egg. Somewhat diagrammatic.

of dark grey, is generally darker in colour, and is about 6 mm. long. This stage becomes again darker and grows to about 10 mm. in length.

Each larval instar lasts 3-4 days. The larger larvae not only gnaw the surface of the leaf but perforate it whilst feeding, as do the adults.

The larvae are gregarious, particularly in the young stages, moving from leaf to leaf en masse. In the field *Cordia* bushes attacked by *Schematiza* show a number of leaves with characteristic skeletonizing by groups of larvae.

At the end of the feeding period the larva spins a very light silken cocoon in which an inactive prepupal stage is passed. In this the larva is sharply curled ventrally and after about two to three days the larval skin is shed to give rise to the pupa (Figure 5) and in this process the larval hairs become attached to the silken cocoon. In the field the prepupa is formed in the debris beneath the *Cordia* bushes, in folded dead leaves, etc., and in the laboratory under blotting paper, leaves etc. at the bottom of the rearing cage or dish. The duration of the pupal stage is variable but averages about 4 days. At first it is yellow, but towards the end of the pupal period the elytra darken somewhat before eclosion of the adult. On emergence the adult is light yellow, but darkens quickly to the mature coloration. As with the egg stage, individuals in the prepupal and pupal stages are very sensitive to drying.

The developmental time of *Schematiza* in Trinidad is about 22 days, of which the actively feeding larval stages account for about 12-13. As with *Physonota* an attempt was made to estimate the damage to *Cordia* caused by the larvae, but owing to the difficulties of determining the actual area eaten and to the uncertain effects on the plant of leaf-skeletonizing this was given up.

Parasites and Predators

No predators have been observed feeding on adult *Schematiza* in the field but larvae have been seen to be carried off by spiders and in one instance by a large ant (? *Ectatomma tuberculatum*). Unlike *Physonota* larvae those of *Schematiza* do not seem to be attacked either by *Solenopsis geminata* (F.) or by *Polistes canadensis*. Kirby and Adamson (1944) state that a small brown and yellow Carabid beetle has been seen devouring *Schematiza* larvae. A Pentatomid bug is also predaceous on *Schematiza*; a nymph, black with yellow spots, was observed in the field feeding on a third instar larva, and a black and red adult attacked an adult beetle in the laboratory. Donald (1945) records that "considerable damage

is also inflicted upon the egg-masses by at least one species of ant which devours the contents". Donald also mentions a Pentatomid predator, *Heteroscelis brenthoides* (Walk.), as feeding on both adults and larvae.

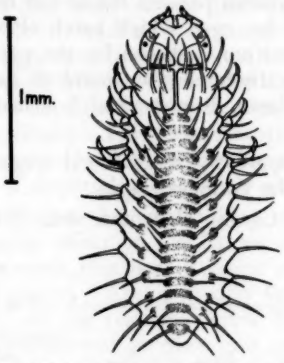

FIG. 4. *Schematiza* 1st stage larva, dorsal view.

Both eggs and larvae are parasitized very heavily in Trinidad (Simmonds 1948). Egg masses collected in September 1946, produced 59 *Schematiza* larvae and 338 parasites (*Tetrastichus* n. sp. in which a single parasite develops in each host egg), a parasitism of 85.1%. Another collection, made a week later, gave 24 larvae and 293 parasites, or 92.4% parasitism. In an October collection 33 egg-masses produced 77 larvae and 302 parasites—79.7% parasitism. These are typical of the parasitism records, and when it is realized that, had the masses not been collected and removed from the field further parasitism might have occurred, the importance of parasites in destroying eggs of *Schematiza* is seen to be very considerable. This was found to be normal throughout the season.

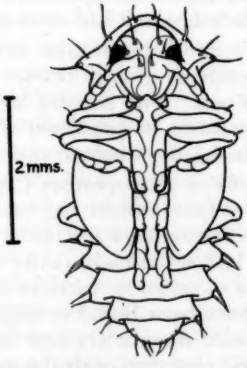

FIG. 5. *Schematiza* pupa, ventral view.

The principal larval parasite found was a Tachinid, *Chaetonodexodes marshalli* Ald., and this itself has a larval parasite, *Spilochalcis* sp. The adult Tachinids may be commonly seen flying around *Cordia* bushes and, although the method of attacking the host larvae has not been studied, it would seem definite that the parasite egg or larva is laid directly on the host. Many thousand *Schematiza* have

been bred in the laboratory on field-collected *Cordia* leaves, and none has ever become parasitized; hence the Tachinid eggs are presumably not laid on the foliage to be subsequently ingested by the host larvae. Since *Schematiza* larvae that have just hatched may contain parasite larvae but not eggs it would appear that female flies larviposit or lay eggs which hatch almost immediately. Little or no avoidance of superparasitism is shown by the parasite; one fairly typical collection of larvae that was dissected was found to be 100% parasitised:—31 hosts contained one parasite larva, 20 contained 2, 8 had 3, 6 had 4 and 1 host contained 6 parasite larvae.

Parasitism may occur apparently at all larval stages from very soon after hatching, but principally in the younger stages.

One collection made at Caroni, December 6th, 1946, is typical. This on dissection gave:—

	Total hosts	Unparasitised	Parasitised	% Parasitism	Hosts with 1, 2, 3, 4, etc. parasite larvae						Total parasite larvae
					1	2	3	4	5	6	
1st stage larvae	14	4	10	71.4	9	1	–	–	–	–	11
2nd stage larvae	86	4	82	95.4	30	28	13	6	4	1	175
3rd stage larvae	47	7	40	85.1	29	10	–	–	–	1	75
Total	147	15	132	89.8	68	39	13	6	4	2	261

Other large collections made at various times were dissected in the laboratory and gave an average parasitism of 93.4% (maximum 100%, minimum 60.5%—excluding figures from those larvae which had obviously only just hatched).

The subsequent development of the parasite larva within the host was not followed closely, but little change or growth occurs until the host larva is fully grown and is forming its cocoon. The parasite larva then grows rapidly and the full-grown Tachinid larva forms its puparium within the empty larval host skin. The puparial stage lasts 6-7 days before emergence of the adult fly.

The hyperparasite, *Spilochalcis* sp. parasitises *Chaetonodexodes* larvae to the extent of about 0.8%. This yellow chalcid has been seen in the field with its ovipositor inserted into a *Schematiza* larva and, from dissection, it has been seen that the egg of the Chalcid is laid in the body cavity of the Tachinid larva when it is still very small. Thus the oviposition reactions of the Chalcid must be very highly developed. No eggs have been found in unparasitised *Schematiza* larvae, hence the ovipositing *Spilochalcis* must select first only *Schematiza* larvae parasitised by *Chaetonodexodes*, and then find with the ovipositor the small Tachinid larvae before laying in the latter.

Spilochalcis adults emerge from the Tachinid puparia some 12 days after the latter have been formed, that is some six days later than the fly would have emerged had parasitism not occurred.

Spilochalcis has at no time been seen to act as an efficient check on the numbers of *Chaetonodexodes* and does not impair this parasite's controlling action on *Schematiza*. This controlling action was further shown by several experiments

in which numbers of unparasitised laboratory-bred *Schematiza* larvae were placed on small *Cordia* bushes in pots isolated on a well-cut grass lawn at least 200 yds. from the nearest *Cordia* bush. Larvae were placed out soon after hatching and collected for dissection 11 days later. Of 50 dissected only one was unparasitised. Of 25 from another such *Cordia* bush all were parasitised. In another experiment two Cordia bushes 1'6" high, each bearing only 10 developed leaves were placed out similarly. Thirty-one *Schematiza* larvae that had just hatched were put on these two bushes. Eleven days later 29 larvae were recovered and dissected; 27 were parasitised, 2 unparasitised. This illustrates strikingly the manner in which *Chaetonodexodes* may locate and parasitise host larvae when on very small *Cordia* bushes, and the powers of dispersal of the adult parasite.

The effect that this parasite has in checking the increase of *Schematiza* in Trinidad and its consequent effect on *Cordia* has already been recorded (Simmonds 1948) and it is obvious that here parasitic control is the main factor in limiting the increase of a species. Approximately 90% of eggs laid are destroyed by *Tetrastichus* and 95% of the resulting larvae by *Chaetonodexodes*. Hence 99.5% of the eggs laid are destroyed by *these two species of parasite alone* before the larvae reach the pupal stage. Since the average numbers of eggs laid in the laboratory (where the adults are protected from any mishap) is 866 it follows that from each pair only approximately 4.3 individuals survive egg and larval parasitism from the progeny of each pair of *Schematiza*. Thus if only 53.5% of these individuals (or 2.3 more of the 866 originally produced) are killed by any other means no increase in the species will occur. General observation shows that this is in fact what occurs normally in Trinidad where *Schematiza* is moderately common always during the wet season. Small localized increases in numbers do occur occasionally but these quickly disappear.

General

In the present investigation the important features of the biology of *Schematiza* are the high fecundity of the females, their apparent power to become dormant during unfavourable (dry) conditions, the fact that in all stages the species feeds only on *Cordia macrostachya* and that it should increase rapidly if freed from the highly efficient controlling action of parasites found in Trinidad. Thus if climatic conditions in Mauritius are favourable for *Schematiza* and there are no native parasites or predators attacking it, the damage caused to *Cordia* and rate of increase of the beetle should be considerable.

The possibility of the occurrence of several races of this species have been indicated by investigation of the black form occurring in Grenada. Apparently this form has habits identical to those of the Trinidad form, but the adult is darker, the eggs on laying are a more golden yellow, and the larvae are of a deeper yellow colour in the early and darker in the later stages. This form has been successfully crossed with the Trinidad form and the black coloration is dominant. All the F_1 adults were of the Grenada type or very slightly lighter. In the F_2 a complete range of colours from light (Trinidadian) to dark (Grenadan) were observed with the dark forms predominating. Thus this coloration does not depend on a single genetical factor. It is probable that with variations in coloration there are also variations in other aspects of the physiology, and it is possible that the optimum conditions for the two forms vary slightly. It might therefore be worth while introducing this form also into Mauritius since it may exert effective control on *Cordia* in areas where local conditions are not favourable for the Trinidad species. It is hoped to publish further results on this elsewhere.

At the present time *Schematiza* has now been liberated in Mauritius. Ship-

ments were sent by air-mail from Trinidad consisting of full-grown larvae and pre-pupae loosely packed with damp moss in wooden boxes or celluloid tubes (for small trial shipments). Packed in this way the species survived 10 days in transit very well, live adult beetles being present on arrival. When longer than this in transit, mortality increased rapidly until, if the period was over 15 days, no living individuals reached their destination. Air-mail was found to be much quicker and more reliable than air-express in making these shipments.

On arrival in Mauritius stocks were bred up and further feeding tests were made. In these *Schematiza* could be induced to feed, though not to oviposit, on several species, particularly cabbage, and it was only some time later that it was decided to make liberations. In at least one area breeding has occurred in the field and the outlook for establishment is promising.

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A New Record of a Flea Beetle, *Chaetocnema* sp., on Corn in British Columbia

During the summer of 1949 an outbreak of flea beetles on both sweet and silage corn occurred at Armstrong, British Columbia. The first damage to the corn was noticed by the growers in early July, and by mid-August was so severe in some instances that the crop had to be cut for ensilage before the cobs were mature. The adult beetles confined their feeding to the leaves and cob husks, causing decided browning and drying out of these areas.

Beetles were identified by H. S. Barber of the U.S. Bureau of Entomology as *Chaetocnema* sp. near *ectypa* Horn. Mr. Barber comments, "Very near (or a northern variety of) *C. ectypa* Horn, having similar aedeagus but rougher sculpture and darker colouring." *C. ectypa* has been reported only from dry regions of southwestern United States, and this is the first record of flea beetle injury to corn in British Columbia.

Armstrong is situated in a mountain valley 5 to 8 miles wide, at an elevation of 1187 feet. The Selkirk Mountains rise 3000 to 5000 feet to the east. The 1948 precipitation was 22.55 inches, but the 37-year average is only 16.88 inches. The 35-year mean temperatures for the summer months are: May, 54°; June, 63°; July, 66°; and August, 64°.

C. L. Neilson.

Book Notices

Natvig, L. R. Norsk Entomologisk Tidsskrift. Suppl. I. Contributions to the knowledge of the Danish and Fennoscandian mosquitoes. Culicini. Messrs. A. W. Briggers Boktrykkeri A/S, Karl Johanns gt. 12, Oslo, Norway. XXII plus 567 pages, 12 plates, 148 figs. 1948. Price Norw. kr. 50.00 (approx. $10.00).

This monographic work is based on the results of field investigations carried out by the author in southern Norway over a period of 18 years, and on a study of mosquito collections in Denmark, Finland, Norway, and Sweden.

It is a monumental work and contains an exhaustive study of the taxonomy of the northern species of culicine mosquitoes, preceded by a detailed account of their external anatomy and a briefer one of their internal anatomy.

The systematic review covers 35 species of culicines known to occur in the area, of which 19 have been recorded in Canada. Tables summarize the characters of some species, and keys are given to the genera and species.

General notes on the biology of the species, besides including Dr. Natvig's own extensive observations, summarize pertinent information from other sources. Of special interest is a chapter reviewing the accounts of the experiences of explorers and others with the very serious mosquito pests in the Far North.

The distribution of the species is given for other parts of the world as well as for Denmark and Fennoscandia. One list of the species recorded in Scandinavia indicates which of them also occur in Siberia and North America.

The monograph is profusely illustrated, most of the figures depicting larval and adult anatomical details of taxonomic significance. There are also a number of maps showing the distribution of many of the species, and several plates of photographs showing typical breeding places.

Dr. Natvig's book is an important and valuable contribution to a knowledge of the northern mosquitoes, and should be in the possession of all who are interested in the study of these serious pest insects. The author proposes shortly to take up work on a monograph on the Anophelini of the same region.

C. R. Twinn

Introducing the Insect: By F. A. Urquhart, with illustrations by E. B. S. Logier. Pp. IX and 287; with 4 coloured plates and 160 numbered text figures and additional text figures illustrating the Keys; Toronto, Clarke, Irwin & Co.; $5.00.

One of the least satisfactory things in modern entomological history is the gradual disappearance of the amateur—the man who works on insects not to make a living but simply for the love of the subject. The high cost of equipment and specialized training for work in fields like physiology and genetics limits the field of work of amateur entomologists. They have usually been collectors, systematists and, less commonly, students of life histories. To them we owe the bulk of the detailed work on the insect fauna of the Old World.

As their hobby takes them frequently into the field, they usually become good general naturalists. A man who has been an enthusiastic amateur naturalist in his teens and goes on into professional zoology or botany possesses, at the outset of his college career a fund of knowledge that he will not easily get from his formal courses.

There is still a fair scattering of capable amateur entomologists in European countries, where they continue to make valuable collections which are the basis of solid contributions to systematic entomology. In North America and particularly in Canada, they have become rare. The meagre band of taxonomists attached

to government and university organizations, already overloaded with the duties of identifying material and caring for collections cannot replace them. This is one reason why we know so little, for example, of the insect fauna of the Province of Ontario. The Entomological Society of Ontario, once an association of amateurs, now contains very few and is not, indeed, at present, organized in such a way that it can be very useful to amateurs.

The great merit of Professor Urquhart's beautifully produced book is that it is designed to produce and encourage a crop of amateur entomologists. It is addressed to persons who know nothing about insects and is planned so as to lead them by easy stages into the study of this fascinating group. Following what is certainly a sound instinct the author begins by explaining in detail how to make an insect collection. He follows this with chapters on insect anatomy and life history and on classification and identification, this latter including an original but probably not superfluous explanation of the use of systematic "Keys". He then takes up the various groups in the usual order, ending with a chapter on galls and a list of reference books. Technical material is reduced to a minimum. Common rather than scientific names are used to designate the groups and types. Only the most common families are included; for example only 28 families of beetles against 109 listed in Comstock's "Introduction to Entomology" and of these 28, only 19 are covered by the Key to the order. However, the types selected are usually those most frequently found in the field so that taken in conjunction with Mr. Logier's admirable text figures, the text gives a good general account of insect structure and life. It cannot replace, for the advanced amateur, such works as Lutz's "Field Book of Insects", which contains in a more compact form a much larger amount of technical information. But it is undoubtedly, for the beginner, a simpler and less confusing introduction to the study of insects. We hope that it has a wide distribution among the persons for whom it has been written.

W. R. THOMPSON

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